On the Measurement of Dynamical Properties of CMEs with the SECCHI Coronagraphs: Issues and Solutions

Angelos Vourlidas, Russ Howard

Naval Research Laboratory

ABSTRACT

With the complement of the coronagraphs and imagers in the SECCHI suite, we expect to be able to follow continuously a coronal mass ejection from the Sun to Earth for the first time. The comparison, however, of the CME emission among the various instruments is not as easy as one might think. This is because the coronagraphs record the Thomson scattered emission from the CME plasma which has a rather sensitive dependence on the geometry between the observer and the scattering plasma. In this talk, we will describe the issues that arise in comparing CME emission over a large range of elongation angles and will outline the solutions we will adopt for the SECCHI observations. More extensive discussion can be found in Vourlidas & Howard (2006).

1. Thomson Scattering Facts

- The emission recorded by white light coronagraphs originates by Thomson scattering of the photospheric light by the electrons within a CME or other coronal structure.
- The emission is composed of radial, I_r and tangential, I_t components. They are derived from the equations in Fig. 1. They depend on two angles: (1) the **angle χ**, between the line of sight and the radial through the scattering electron, and (2) the **elongation Ω**, of the solar limb as seen by the scattering electron.
- The actual observables are the total **$B = I_t + I_r$**, and polarized **$pB = I_t - I_r$** brightness.
- The emission is maximum when the LOS is normal to the radius through the scattering electron, χ = 90º. This is commonly called the *plane-of-the-sky* and corresponds to the plane of the solar limb as seen by the observer.

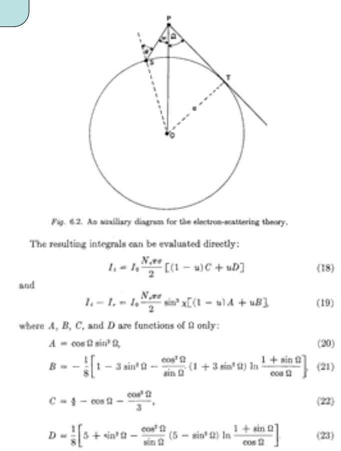

Figure 1: Thomson scattering formulas and geometry (from Billings (1996), page 148).

2. Scattering Geometry

For large elongations the location of the maximum scattering does not lie on a plane but on a spherical surface (we call it "Thomson Surface") centered half-way between Sun and observer. To treat the brightness of CMEs self-consistently over large elongations (as is the case for SECCHI), we need to make two adjustments:

1. The lines of sight should not be assumed parallel to the Sun-observer line.
2. The analysis should be made relative to the Thomson surface and not the plane of the sky.

But what do these changes in the brightness calculation imply for past and future CME analysis?

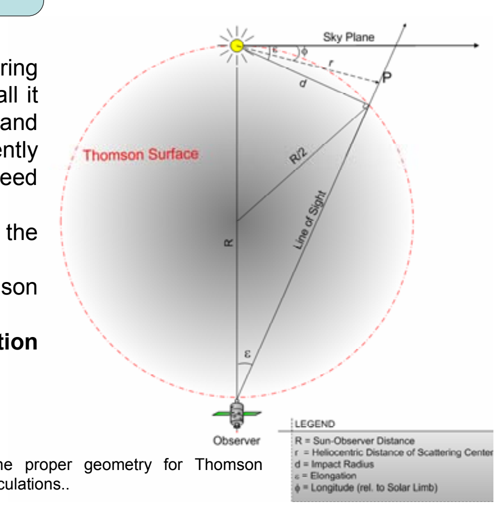

Figure 2: The proper geometry for Thomson scattering calculations..

3. Comparison to Standard Assumption

- The default assumption for all brightness measurements has been to equate the plane of the solar limb to the maximum scattering plane or "Thomson surface". But this is assumption is not correct at larger elongations. **Where does this assumption break down?**
- Fig. 3 reveals that the standard assumption **holds** easily for brightness calculations **out to at least 70 R_{sun}**.
- There is no need to reexamine past work/results.
- This formulation allows us to explore the behavior of the CME brightness over large elongations. What are the implications?

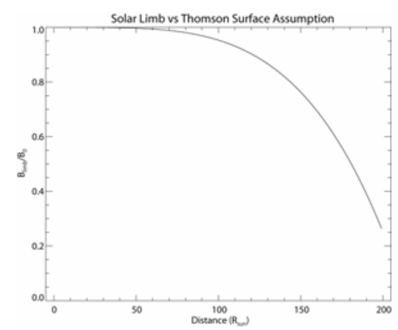

Figure 3: Range of validity of the plane-of-the-sky assumption currently used for CME brightness calculations. The ratio $B_{limb}/B0$ is the ratio of the brightness calculated using the assumption over the brightness derived from the full treatment.

4. Implications

The "Thomson surface" presents us with a changing plane of maximum scattering instead of the constant plane-of-the-sky. **How does this affect the brightness of CMEs ejected at different longitudes?**

In Fig. 4, we plot the brightness versus elongation for a single electron propagating radially at various heliocentric longitudes (the solar limb is at 0º). The plot indicates that:

- CMEs originating at the solar limb have a sharp brightness drop for > 150 **R_{sun}**.
- CMEs originating at other locations tend to reach the limiting brightness for > 30 **R_{sun}**.

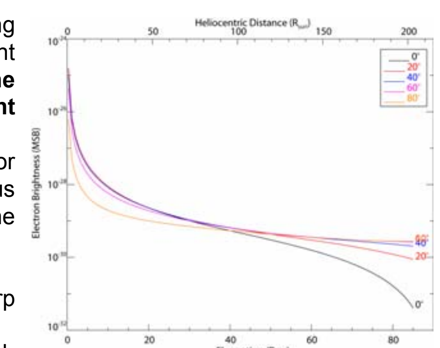

Figure 4: The brightness of a single electron as a function of elongation or distance for various distances from the solar limb (located at 0º).

Since the true extent of a CME is unknown, the total mass was always calculated assuming that is concentrated on the plane of the sky. The effect of this assumption on the masses has been discussed by Vourlidas et al (2000). **How does the new methodology affect the masses?**

In Fig. 4, we show the result for the simple case of a CME of zero width propagating radially along the given latitudes (the limb is at 0º). The y-axis gives the ratio of the "real" to the derived mass under the standard assumption that all mass is on the surface of maximum scattering.

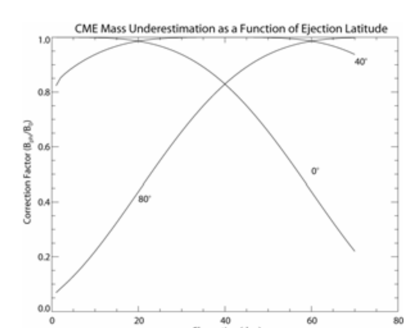

Figure 5: The underestimation of the mass of a CME having zero width and propagating radially from a given latitude as a function of elongation.

5. SECCHI Analysis

The SECCHI coronagraphs will observe CMEs over the full range of elongations we have considered here. Therefore, we need to apply the full scattering treatment to the analysis of all 4 SECCHI coronagraphs to derive consistent results. This implies the following:

1. The solar limb is no longer the plane of maximum scattering. The Thomson surface is..
2. The CME mass will be calculated assuming that all electrons are on the Thomson surface.
3. Projected quantities will be given as a function of elongation.

6. Example Application

A simple example can help clarify how the mass analysis of SECCHI images could make use of the concepts we outlined here.

1. Each image (from COR1, COR2, HI1, HI2) is calibrated in MSB according to the instrument's procedures.
2. A suitable preevent image is subtracted to provide an excess mass image.
3. The CME mass in each frame is calculated assuming that all electrons are on the Thomson surface.
4. The elongation of the derived center-of-mass is used as a representative location for the CME at the given frame.
5. We then locate the CME masses on a plot of mass versus elongation where traces of mass for CMEs propagating along different longitudes (similar to Fig. 4, for example) are also shown.
6. We expect that the SECCHI masses will closely follow one of the curves, therefore revealing the most likely propagation angle of the particular CME.

References

Billings, D.E. 1966, Guide to the Solar Corona

Vourlidas, A et al, 2000, ApJ, 534, 456

Vourlidas, A. & Howard, R.A., 2006, ApJ, submitted